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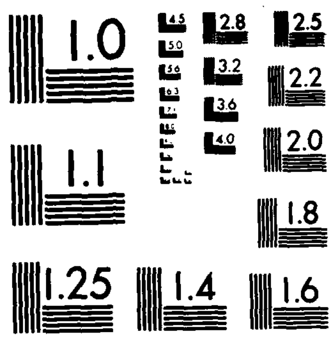

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VISIBLE-LIGHT RESIN CURING UNITS: RETINAL HAZARDS AND PROTECTIVE LENSES

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This document presents an assessment of the potential retinal hazard of dental visible-light photopolymerization units and the efficacy of protective lenses for reducing the potential hazards. The spectral radiance profiles of 11 visible-light photopolymerization units were measured; and the results were then weighted according to the American Conference of Governmental Industrial Hygienists (ACGIH) Blue Light and Thermal Hazard Functions. The results indicate that there are no thermal hazards to the retina even for the worst case condition. None of the blue-light hazard maximum permissible exposure times is short enough to be of concern unless the individual operator chooses to focus on the light source for an extended period. Those individuals who elect to stare at the light during curing procedures should consider the purchase of protective lenses. The special transmission profiles of 16 protective lenses were measured and new permissible exposure limits calculated for each lens/unit combination. All lenses but one were effective in reducing the potential blue-light hazard.

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VISIBLE-LIGHT RESIN CURING UNITS: RETINAL HAZARDS AND PROTECTIVE LENSES

INTRODUCTION

Visible-light cured resins are an outgrowth of the ultraviolet (UV) light-cured resins and are single paste systems possessing photoinitiators that absorb light in the 420 to 450 nm range. Polymerization is induced by the production of free radicals. The visible-light resin curing units designed to initiate polymerization are high-intensity light sources with outputs concentrated in the 400- to 550-nm region (primarily the blue portion of the visible spectrum). Recently several articles have mentioned the potential for retinal damage from the light emitted by these visible-light resin curing units (1-5).

Light within the spectral range of 400 nm to 1400 nm is transmitted through the ocular media (cornea, aqueous, lens, and vitreous to the retina) and can be associated with three types of retinal damage: structural damage is caused by sonic transients and is associated with mode-locked or Q-switched lasers; thermal damage results from exposure to light sources of sufficient power levels and duration to raise the retinal temperature 10°C or more above ambient; and photochemical damage results from short wavelength light at power levels below that required for thermal damage (6,7).

The photochemical (also called blue-light) hazard has received a great deal of attention recently. Many manufacturers are advertising glasses or other filtering lenses to eliminate or reduce the potential blue-light hazard from the visible-light resin curing units.

The purpose of this study was to evaluate the potential for retinal damage from commercially available visible-light resin curing units and to determine the efficacy of commercially available lenses advertised to prevent this damage.

TEST METHODS

Potential Retinal Hazards

Visible-light resin curing units from 11 manufacturers were evaluated (Table 1). For all units with a variable intensity control, measurements were made at the highest intensity setting.

Radiance Measurements

A Pritchard 1980b Spectroradiometer (Photo Research Division, Kollmorgen, Burbank, CA) was used to measure the spectral radiance output of each unit from 370 nm to 730 nm in 10 nm increments. For infrared (IR) measurements, a black detector calorimeter, consisting of a black detector thermocouple connected to a Keithley 148 nanovoltmeter (Keithley Instruments, Inc., Cleveland, OH), was used to measure the energy output of the light.

Measurements were made without filters between the light and detector, and then with a Schott KG-3 IR blocking glass filter (Schott Optical Glass, Duryea, PA), which also blocks approximately 20% of the visible light. A Ralph Gerbands Co. shutter was used on the light to control exposure duration. Several measurements were made for each condition, and a ratio of the IR energy to visible energy was calculated. Multiplying these ratios by the integrated visible spectral radiances measured by the Pritchard 1980b allowed the integrated IR spectral radiance to be calculated.

Thermal Hazard Calculation

To assess the potential of the resin curing units to produce retinal thermal injury, the spectral radiance profiles of each light were weighted according to the potential of its component wavelengths to produce retinal damage by using the American Conference of Governmental Industrial Hygienists (ACGIH) spectral weighting functions for the thermal hazard (Table 2) (8). The thermal hazard function extends from 400 to 1400 nm with a peak at 440 nm. A representation of the thermal hazard function is shown in Figure 1.

The resulting weighted spectral radiances were then integrated according to the proposed ACGIH chronic hazard formula:

$$\sum_{400}^{1400} L\lambda \cdot R\lambda \cdot d\lambda \quad 1/\alpha t^{1/2} \tag{1}$$

where $L\lambda$ = spectral radiance in watts/cm^2 Sr
$R\lambda$ = thermal hazard function value
λ = *wavelength in nm*
α = angular subtense of the source in radians
t = viewing duration limited to 1 μm to 10 s

A worse case distance of 25 cm (10 in.) was chosen to calculate the value of α.

Blue-Light Hazard Calculation

The blue-light or photochemical hazard calculation was performed using the ACGIH Blue-Light Function (see Table 2) (8). The Blue-Light Hazard Function also peaks at 440 nm, but drops to insignificant levels above 600 nm. A representation of the Blue-Light Hazard Function is shown in Figure 1.

The weighted spectral radiance values for each resin curing unit were integrated using the proposed ACGIH Blue-Light Chronic Hazard Formula:

$$\sum_{400}^{1400} L\lambda \cdot B\lambda \cdot t \cdot d\lambda \leq 100 \text{ Joules/cm}^2 \text{ Sr} \quad \text{for } t \leq 10^4 \text{ s} \tag{2}$$

where $L\lambda$ = Spectral radiance in watts/cm^2 Sr
$B\lambda$ = Blue-Light Hazard Function Value
t = time in seconds
λ = wavelength in nm

Solving for the maximum permissible exposure duration (t_{MAX}), the equation becomes:

$$t_{MAX} = 100 \text{ Joules cm}^{-2}\text{Sr}^{-1} / \sum_{400}^{1400} L\lambda \cdot B\lambda \cdot d\lambda \qquad (3)$$

This formula assumes a pupil diameter of 2-3 mm. A worst case of direct viewing from a distance of 25.4 cm (10 in.) was assumed with the same area of the retina being chronically exposed.

Protective Lenses - Test Methods

Seventeen tinted protective lenses from 14 manufacturers were evaluated (Table 3). Lenses 1 through 9 are advertised specifically for use with visible-light resin curing units. Lenses 10 through 16 have been mentioned in other articles for use as protection against the blue-light hazard (1,9) or represent commercially available lenses which have the potential for blocking short wavelength light in the blue region of the visible spectrum. Lens 17 are the stocklisted green glasses currently available in most U.S. Air Force Dental Clinics.

Transmission Profile Measurements

The spectral transmission profiles from 380 nm to 900 nm were measured for each lens using a Cary Model 17 Spectrophotometer (Cary Instruments, Monrovia, CA). This instrument measures the percentage of light transmitted by the lens at each wavelength.

Thermal Hazard Reduction Assessment

Since the thermal hazard calculations showed no thermal hazard was present even for the worst case condition, no thermal hazard assessment using the protective lenses was accomplished.

Blue-Light Hazard Reduction Assessment

The spectral transmittance values for each lens were used to adjust the spectral radiance values for each of the 11 curing units. This adjustment was accomplished by substituting the value of $L\lambda$ in the Blue-Light Hazard Formula with the product of $L\lambda$ and $T\lambda$ where $T\lambda$ is the transmittance value for the lens. The new formula for calculating the maximum permissible exposure duration (t_{MAX}) then became:

$$t_{MAX} = 100 \text{ Joules cm}^{-2}\text{Sr}^{-1} / \sum_{400}^{1400} L\lambda \cdot T\lambda \cdot B\lambda \cdot d\lambda \qquad (4)$$

Luminous Transmittance Calculation

To assess the ability of the operator to see through the lenses, the luminous transmittance of each lens was calculated. The luminous transmittance is a function of the spectral transmittance of the lens weighted by the corresponding ordinates of the photopic luminous efficiency distribution of the CIE (1931) standard colorimetric observer and by the spectral intensity

of standard illuminant C (10). This calculation was done at 10-nm increments from 400 nm to 780 nm. The calculation allows a numerical representation of the amount of visible light transmitted by the lens for a standard light source taking into consideration the sensitivity of the human eye to detect that portion of the visible spectrum.

RESULTS

Potential Retinal Hazards

Spectral Radiance Measurements

The spectral radiance profiles from 370 to 730 nm for each of the 11 units are shown in Figures 2-12. The peak radiance values for the first peak are shown in Table 4 along with the wavelengths at which the peak value occurs. Note that some units have peak radiance values at much higher wavelengths than the most effective curing area of the spectrum. Table 5 gives the integrated visible radiances for each unit and the ratio of the non-visible output (primarily IR) to the visible light output. The integrated visible radiance values represent the total visible energy produced by each unit.

For individuals who desire more information on other aspects of the visible-light resin curing units refer to Aeromedical Review 2-84, "Visible Light Resin Curing Units" (11)*. This review covers areas such as curing effectiveness, maintenance, and cost.

Thermal Hazard Calculations

Table 6 gives the results of the thermal hazard calculations. The ACGIH hazard formula is only valid for the range of 10 μs to 10 s. For longer periods, cooling of the retina balances heating until equilibrium is reached. None of the units had a great enough weighted integrated spectral radiance to give a hazard time of 10 s or less. The results listed in Table 6 represent the fraction of the weighted integrated spectral radiance required to produce a 10 s exposure limit. Even the most hazardous unit only produced a total weighted output that was approximately 17% of the value allowed for a 10 s exposure.

Blue-Light Hazard Calculation

Table 7 gives the maximum permissible exposure (t_{MAX}) values calculated from the blue-light hazard formula. The formula sets a Threshold Limit Value (TLV) of 100 $J/cm^2 \cdot Sr$ for exposure times up to 10^4 s (167 min) (8). The maximum permissible exposure duration, or t_{MAX}, can be calculated by dividing the maximum permissible exposure by the weighted radiance. The t_{MAX} values ranged from 2.4 min to 16 min. Note that the units that have the shortest allowable t_{MAX} and thus present the greatest hazard potential are not necessarily those units that have the greatest total output of energy as indicated by Table 5. Similarly, the unit that appears to be the brightest is not

*No sensitive information is presented from the limited distribution report.

necessarily the unit which presents the greatest hazard potential. The range of the visible spectrum to which the human eye is most sensitive is not the same as the peak portion of the blue-light hazard function.

Protective Lenses

Transmission Profiles

The spectral transmission profiles of the 17 lenses are shown in Figures 13 to 29. The values are expressed as a percentage with 100% indicating total transmission of the light at that wavelength.

Blue-Light Hazard Reduction Assessment

Table 8 lists the maximum permissible exposure (t_{MAX}) duration for all the lens/unit combinations including the t_{MAX} for each unit without any lens for comparison purposes. The t_{MAX} duration represents the maximum recommended amount of time one may safely look at the light source from a distance of 25.4 cm (10 in.) through the indicated lens during a 24-h period. Lens/unit combinations marked with an * indicate t_{MAX} durations in excess of 10^4 s (167 min) with a total weighted, integrated spectral radiance value below the level considered potentially hazardous even for continuous exposure.

Luminous Transmittance

The luminous transmittance values for each lens are listed in Table 9. A value of 1.0 would indicate 100% transmittance at all wavelengths (no lens). The higher the value, the more visible light transmitted to which the human eye is most sensitive, the better the observer should be able to see through the lens. The lens color is also listed in Table 9 for comparison purposes.

DISCUSSION

Resin Curing Units Light Output and Potential Retinal Hazards

Although the most effective band for curing is in the blue to blue-green region of the electromagnetic spectrum, several units (A, C, E, F, K) had peak outputs toward the red or IR regions. One unit, the Kavo Vicon (Unit F) is a general purpose light source designed for fiber optic illumination as well as photopolymerization so one would expect it to have a broader output across the entire visible spectrum. It is interesting that the Midwest Insight II (Unit E), another multiple use light source, uses a blue filter over the photopolymerization portion of the output to reduce the output in the less effective curing portions of the visible spectrum.

Contrary to UV light, whose potential hazard is primarily to the cornea of the eye, visible-light photopolymerization units produce their effect on the retina. <u>The results of the calculations for the thermal hazard show clearly that no thermal hazard exists for any of these units</u>. Their total energy output is fractions of that required to produce any thermal damage to the retina.

The results of the maximum permissible exposure calculations for the blue-light hazard are not as clear cut as those for the thermal hazard. At this point a brief discussion of the literature concerning the blue-light hazard should prove helpful since it is this aspect which has received the most attention in recent dental literature and advertisements.

The photochemical (blue light) hazard was the first mentioned as a separate and unique mechanism of retinal damage by Dr. W.T. Ham and Dr. H.A. Mueller (12). Since that time Dr. Ham and other researchers have investigated this mechanism by using both monochromatic lasers and some broad band optical sources (7, 12, 13) using rhesus monkeys as the primary object of retinal exposure. Although the specific mechanism of action is not known, it is known that the retinal damage occurs at power levels below that required for thermal injury and the effects are most profound with short wavelength (400 - 500 nm) light with the peak at 440 nm (14). The photochemical lesion is a distinct and unique funduscopic lesion, differing from the thermal lesion both clinically and histologically (7). Studies have correlated the photochemical lesion produced with a loss of visual acuity (7).

Although the majority of the studies have used acute exposures, it is postulated that the chronic effects of the exposure may be cumulative (15). The repair process or recovery time appears to be slower than required for corneal epithelium following UV insult (7, 16, 17). Dr Ham has stated that the exposure to short wavelength visible light in bright sunlight may be a cause of senile macular degeneration (6). This argument has been extended to exposure to the output from the visible-light photopolymerization units. Unfortunately, the chronic effects on the human retina have not been adequately studied. Based on the existing research data, the ACGIH has proposed exposure limits. These limits were used as the basis for the calculations in this study. A discussion of the exposure limits and other aspects of high intensity light sources is available (18, 19).

It is important to remember that for the ACGIH hazard formula to be valid the following conditions must exist:

- The same area of the retina must be chronically exposed. For t_{MAX} values over a few seconds means that the observer must focus on the light so that the light is repeatedly concentrated on the fovea.

- Pupil diameter of 2-3 mm.

- Intact lens. Aphakic individuals who have had their lenses removed would be much more susceptible to short wavelength light unless a replacement lens with UV and blue light blocking tints is used.

The maximum permissible exposure time values (t_{MAX}) calculated for the blue-light hazard of the 11 units tested ranged from 2.4 min to 16.4 min for a 24-h period. These values do not appear to be short enough to be of practical concern especially when you consider that spectral reflectance from the surrounding teeth and soft tissue should increase these values and thus decrease the hazard. Ellingson (5) reported an increase in the hazard times by a factor of 4 to 7 using a Lambertian surface with 100% reflectance. Reflectance from oral structures should increase the hazard times to a

greater degree. The brightness of the lights makes it highly unlikely that one could accidentally view the output of the light for even the lowest calculated time. Patients appear to be at no risk especially considering the acute angle required for them to view the light output. The t_{MAX} times are only valid if the same area of the retina is exposed. Thus, the dentist or assistant would have to purposefully overcome the natural aversion response to bright light, stare at the light, and focus the light repeatedly on the fovea to approach the t_{MAX} times calculated. The glare can, however, produce distracting afterimages. For those individuals who elect to stare at the light or who wish to prevent the afterimages, there are many highly effective lenses commercially available which are effective in filtering out the short wavelength light.

Protective Lenses

All of the lenses currently advertised to reduce or eliminate the blue-light hazard were effective in blocking out light in these wavelengths. It is interesting to note that they all appeared orange in color. Two other lenses designed primarily for laser applications (lenses 10 and 11) also appeared orange and were effective blue-light blockers. The lenses which appeared yellow (lenses 12 and 13) were generally less effective than the orange tinted lenses but still increased the maximum permissible exposure dramatically for most units. The UV 400 (lens 16), an almost clear lens recommended by Pollack and Lewis (1) did not increase the maximum permissible exposure hazard times appreciably and may not offer sufficient protection for the operator who chose to stare at the light output from the units. The remaining lenses were red (lens 15) and brown (lens 14) in color and, while effective in blocking the blue-light portion of the spectrum, they were very dark and could greatly decrease an individual's ability to see. The green stocklisted lenses (lens 16) greatly increased the t_{MAX} values but were also very dark and could hamper an individual's ability to see.

The choice of the type of protective lens depends upon the clinical technique of the operator and individual desires. As noted earlier the maximum permissible exposures for the units without any protective lenses are sufficiently high that retinal damage from accidental viewing is unlikely.

Special protective glasses or clip-on lenses offer some distinct disadvant--es in the process of reducing the potential blue-light hazard. Wearing glasses may affect the operator's ability to shade match. Because color perception depends on the relative proportion of the various wavelengths in the optical spectrum of an object, colored filters alter the color of objects. Objects with differing spectra which match in color under one light source (metamers) may not match at all when viewed through colored filters (20). This effect is alleviated to some extent by chromatic adaptation, but this adaptation can only be of limited importance since virtually all of the blue wavelengths are blocked by these lenses (21). Another potential problem is that of long-term changes in color vision induced by wearing colored glasses. The predominant changes last from 10 min to several hours, but some effects have been reported to last for several months after removal of the glasses (22).

Another disadvantage to clip-on type lenses is that some operators do not like the additional weight on the bridge of their nose. The Efos Shield (lens 3) and the Cure Shield (lens 2) are designed to block the wavelengths of concern without using glasses. The Efos Shield attaches to the tip of the curing unit to block the light near its source. The disadvantage to this method is that the shield must be adjusted depending on whether you are curing from the facial or lingual. Lingual curing adjustments are sometimes hard to accomplish. The Cure Shield is simply a hand-held paddle which is held over the light source during curing. Its disadvantage is that it requires an additional hand to hold the shield, and that hand may not be available unless the assistant remains chairside to help during the curing process. Use of either of these "non-glasses" type lenses should not affect color perception as long as viewing through the paddle or lens is not prolonged.

The amount of visible light transmitted varied greatly even for the orange lenses. For the orange lenses, all of which effectively blocked the blue wavelength light, the luminous transmittance varied from a low of 0.274 for the BPI 550's (lens 1) to 0.566 for the Cure Shield paddle (lens 2). The larger the luminous transmittance value, the more visible light which is permitted to pass through the lens and the better the operator should be able to visualize the task. Use of the yellow Noviol lens would increase the luminous transmittance to 0.808 and still decrease the potential blue-light hazard dramatically for most units.

The final choice of whether or not to use a protective filtering lens and which lens to purchase will depend on the light curing unit being used, the individual operator's clinical technique, desire for consistent shade matching, and personal preference.

CONCLUSION

This study evaluated the light output of 11 commercially available visible-light photopolymerization units and calculated hazard times for the potential thermal and blue-light hazards to the retina using proposed ACGIH guidelines. The units pose no thermal hazard to the retina. The blue-light hazard times ranged from 2.4 to 16 min/day depending upon the photopolymerization unit measured. These values are large enough that accidental exposure to the light should not be of concern. Those individuals who elect to stare at the light source or reflected light during the curing procedure should consider the use of protective filtering lenses.

All lenses advertised specifically for this purpose were effective in blocking out the wavelengths of concern. All lenses appeared orange. Other available lenses designed for other purposes were also effective, but the yellow lenses were less effective than the orange lenses and the red and brown lenses appeared to be too dark to allow ready visualization of detailed dental tasking. The choice of a specific type of lens depends upon the individual operator's ability to shade match with the lenses and with their preference regarding impact on their clinical technique.

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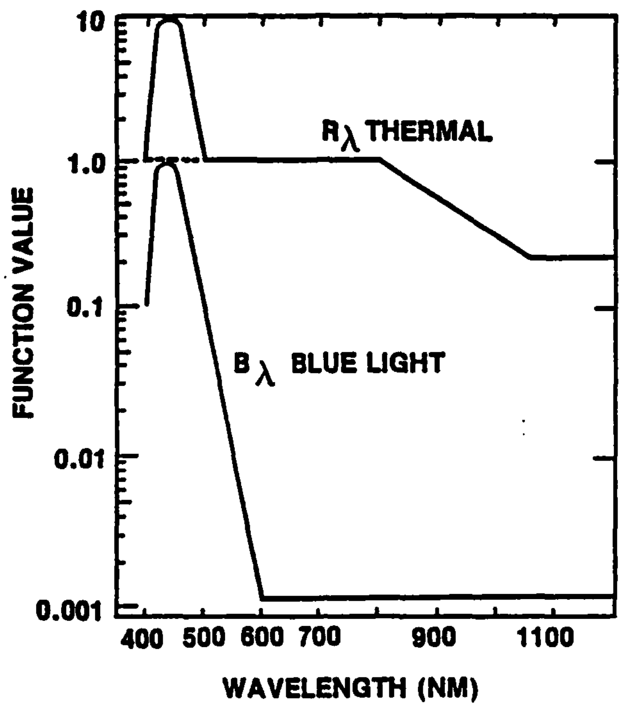


Figure 1. Retinal hazard spectral weighting functions.

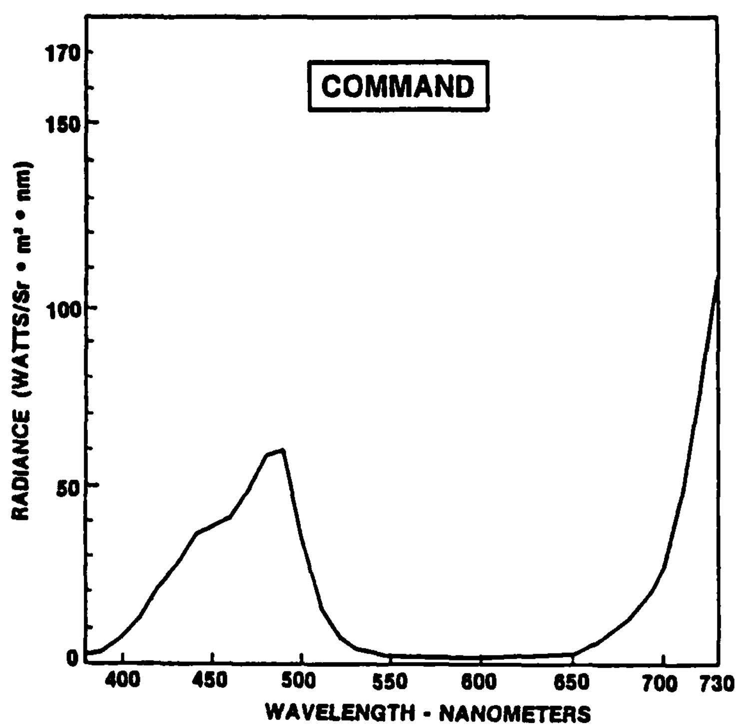


Figure 2. Unit A - peak radiance of 113.4 watts/$Sr \cdot m^2 \cdot nm$ at 730 nm.

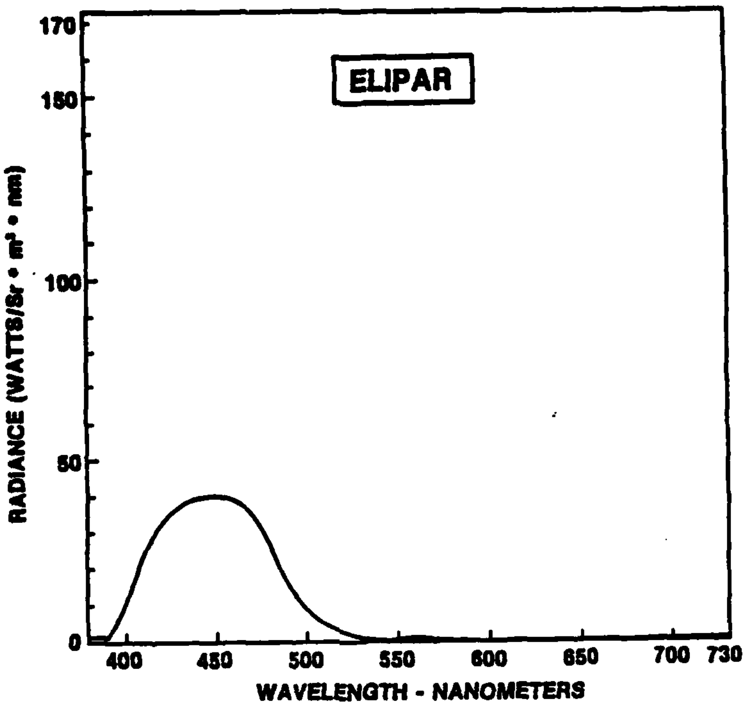


Figure 3. Unit B - peak radiance of 40.3 watts/Sr·m^2·nm at 440 nm.

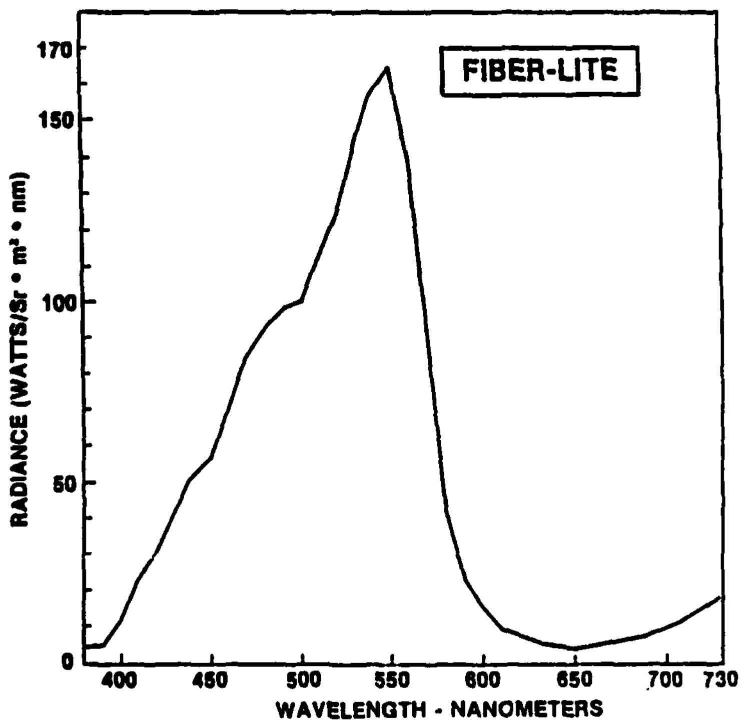


Figure 4. Unit C - peak radiance of 164.3 watts/Sr·m^2·nm at 550 nm.

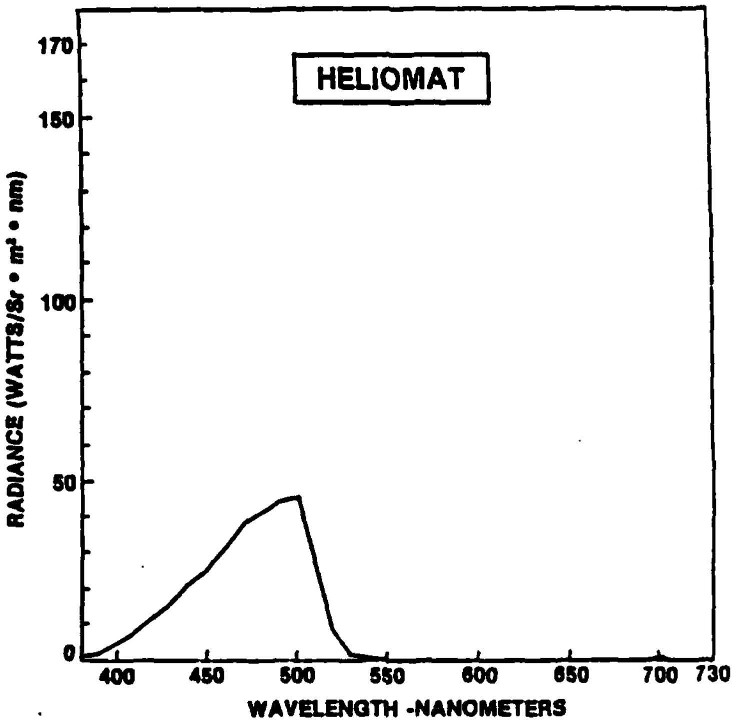


Figure 5. Unit D - peak radiance of 45.1 watts/Sr·m^2·nm at 500 nm.

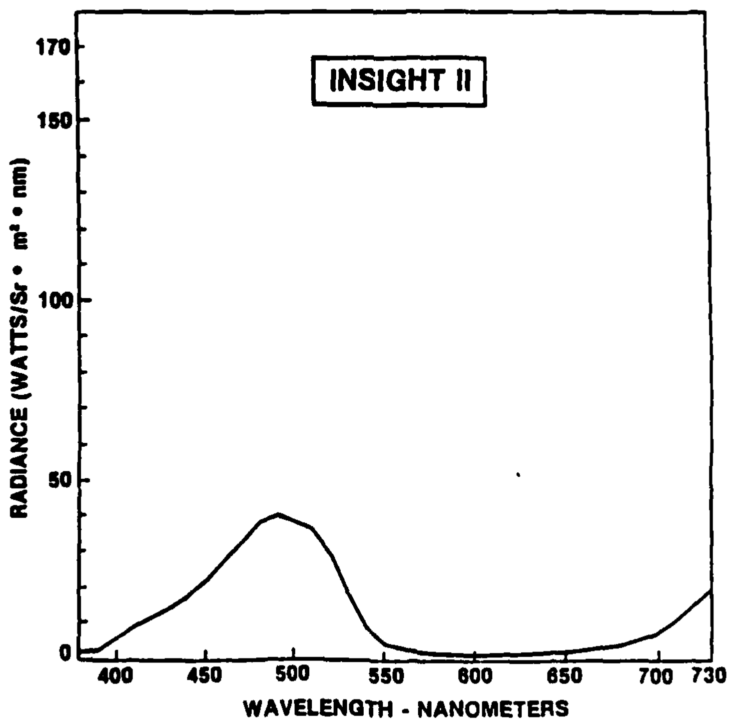


Figure 6. Unit E - peak radiance of 40.3 watts/Sr·m^2·nm at 490 nm.

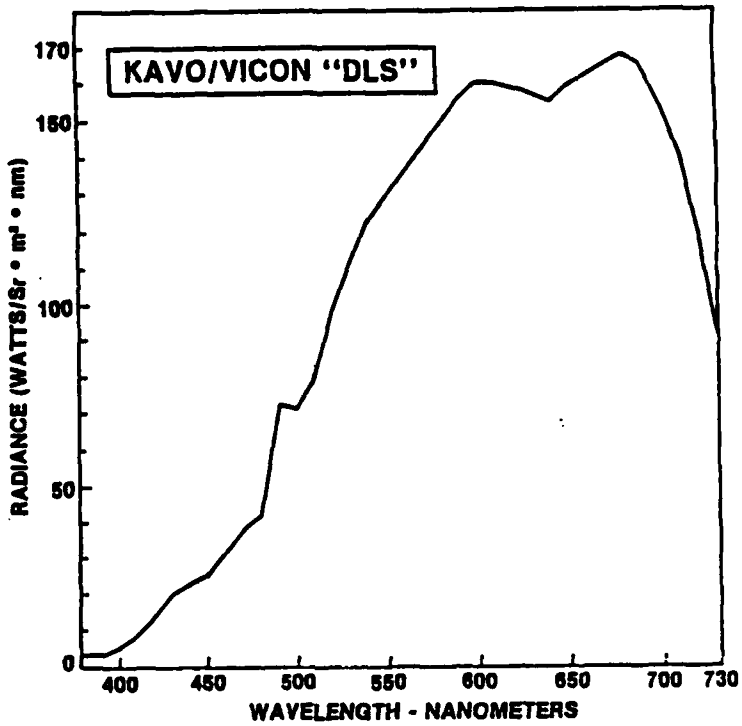


Figure 7. Unit F - peak radiance of 168.4 watts/Sr·m^2·nm at 680 nm.

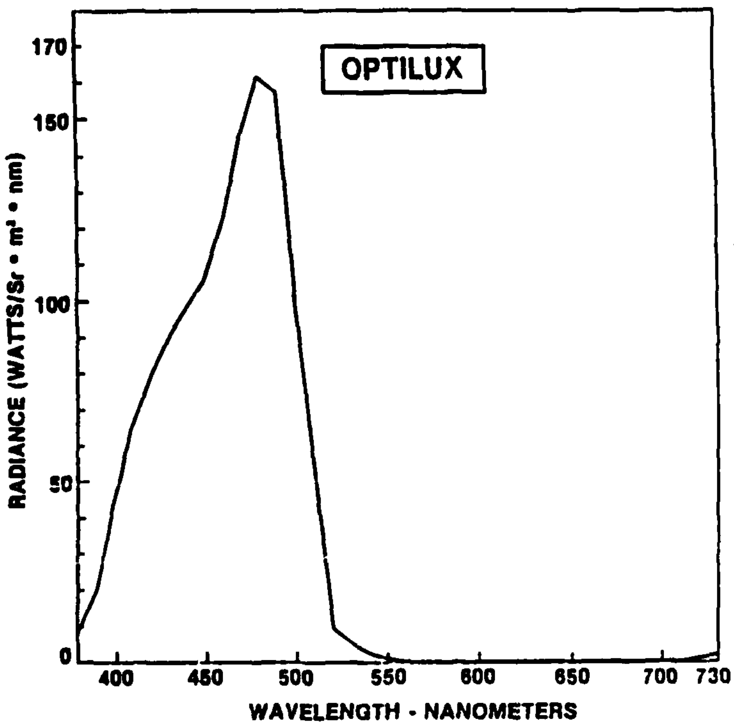


Figure 8. Unit G - peak radiance of 161.4 watts/Sr·m^2·nm at 480 nm.

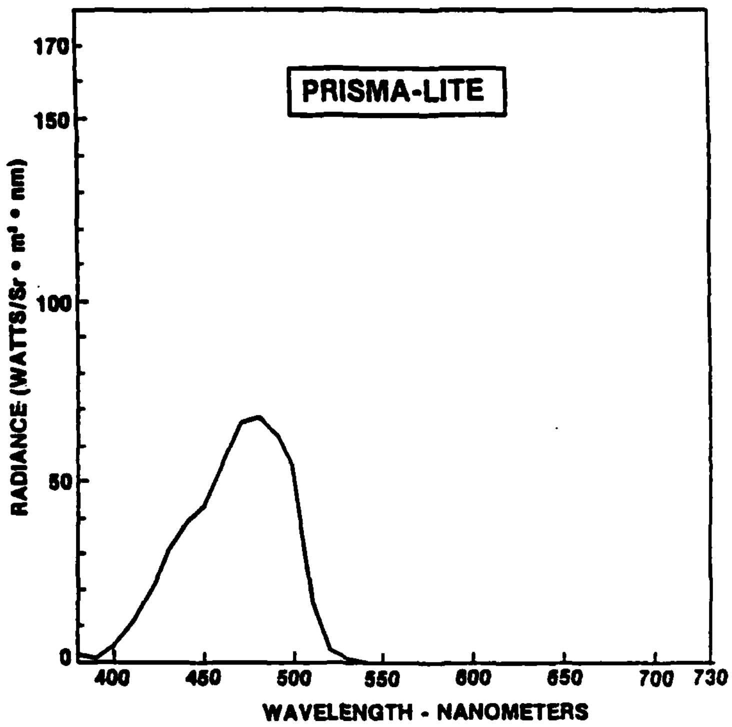
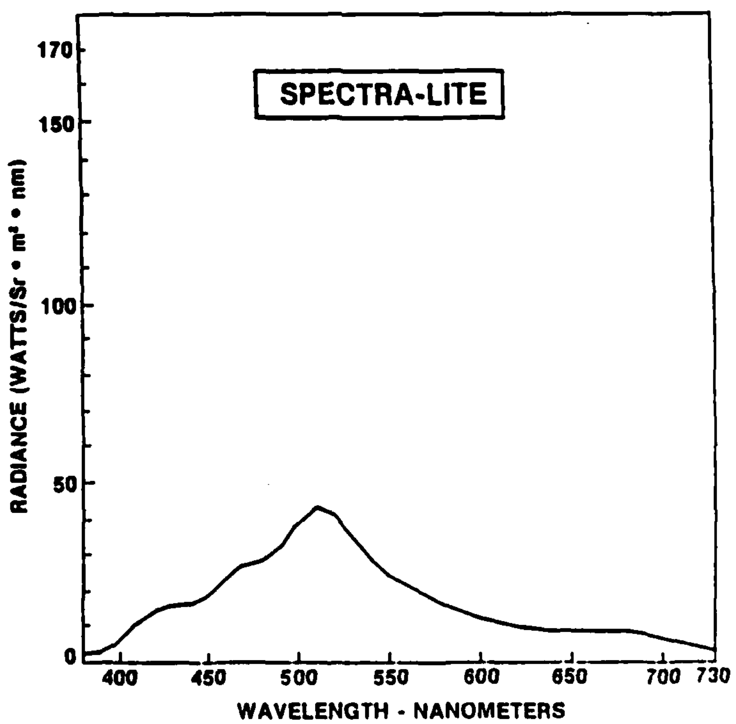


Figure 9. Unit H - peak radiance of 68.1 watts/Sr$\cdot$m$^2\cdot$nm at 480 nm.



Figur 10. Unit I - peak radiance of 44.1 watts/Sr$\cdot$m$^2\cdot$nm at 510 nm.

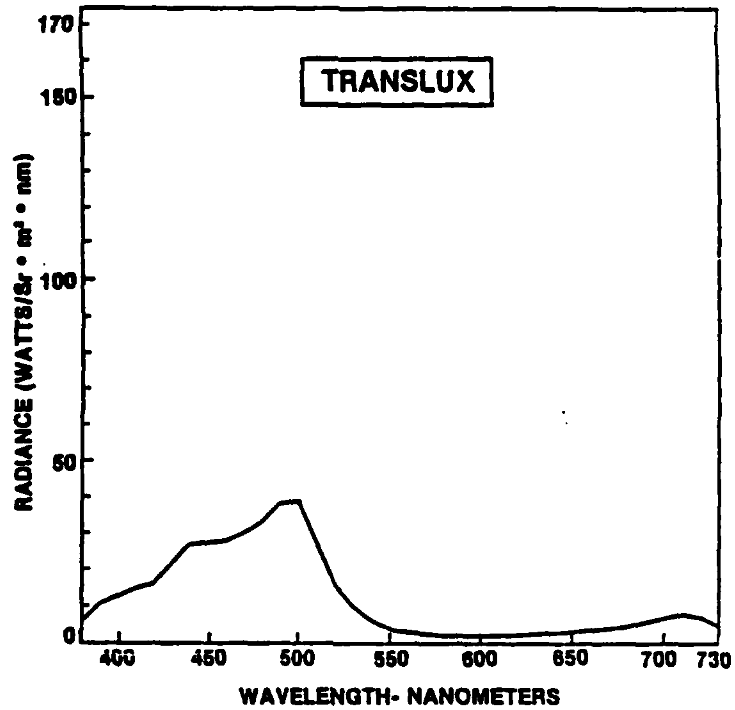


Figure 11. Unit J - peak radiance of 39.5 watts/Sr$\cdot$m$^2\cdot$nm at 500 nm.

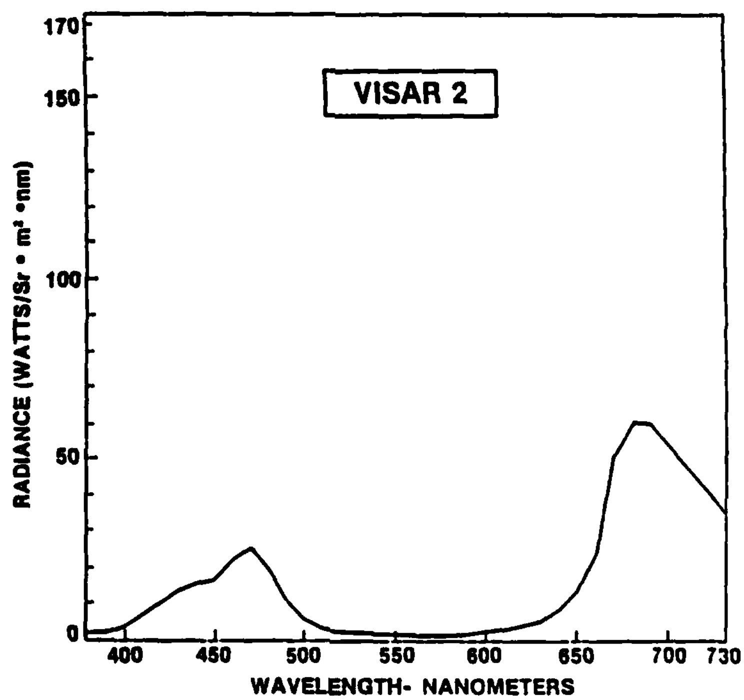


Figure 12. Unit K - peak radiance of 60.4 watts/Sr$\cdot$m$^2\cdot$nm at 690 nm.

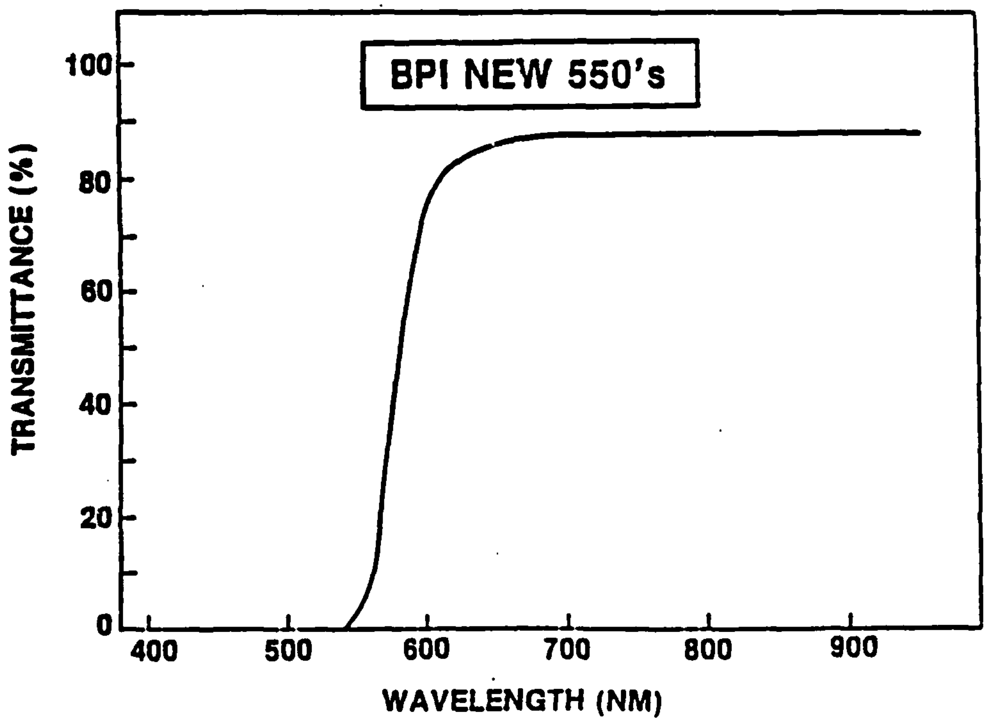


Figure 13. BPI new 550's/lens color = orange.

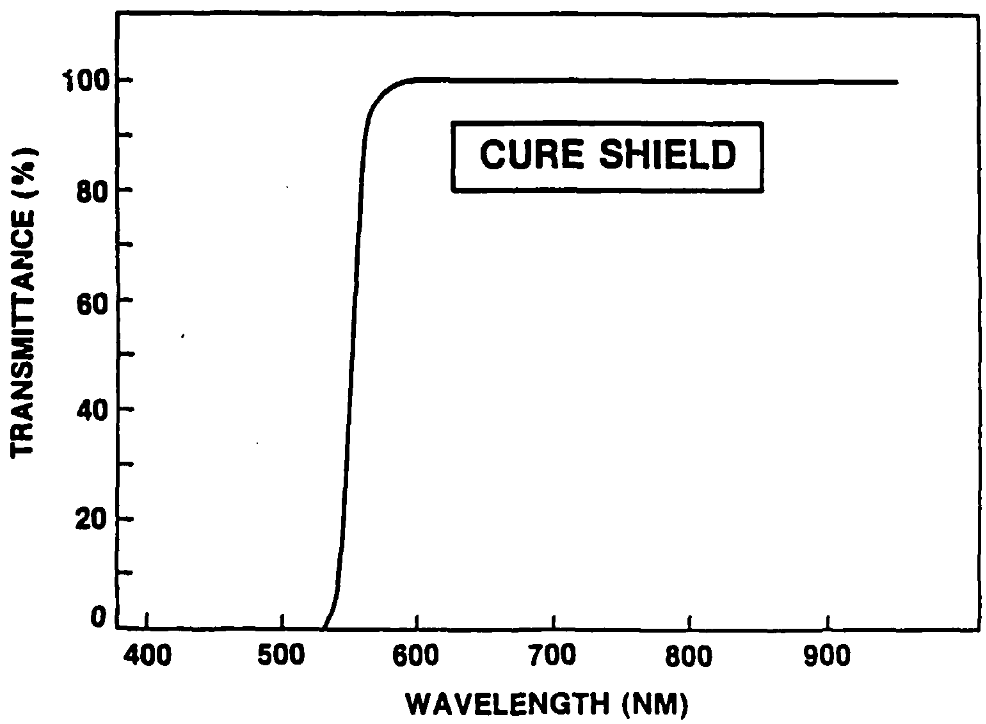


Figure 14. Cure shield/lens color = orange.

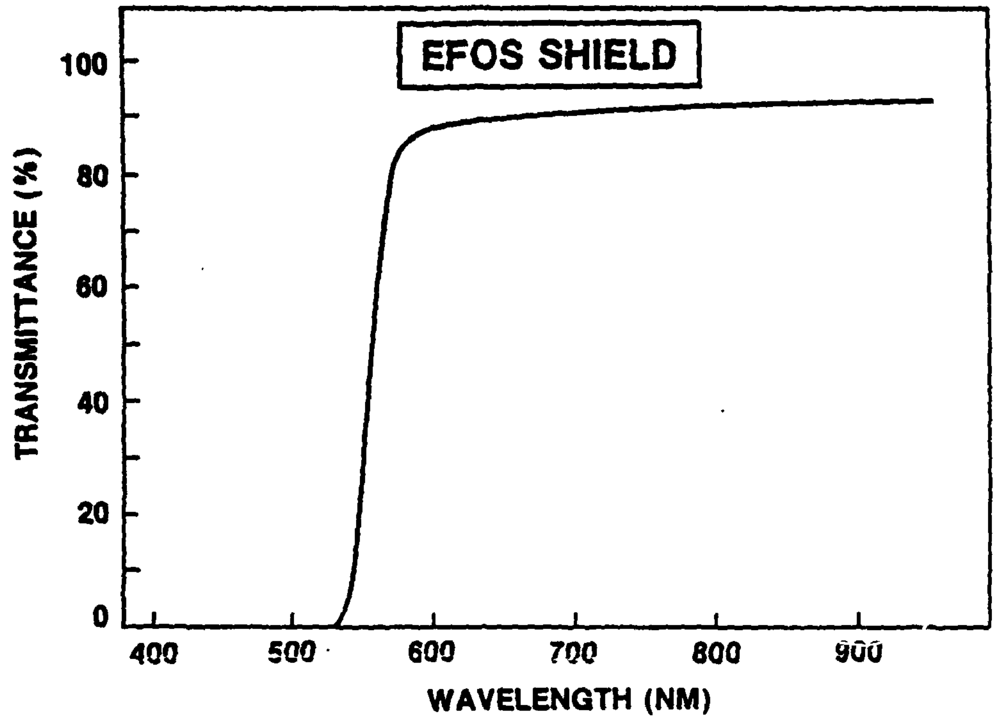


Figure 15. Efos shield/lens color = orange.

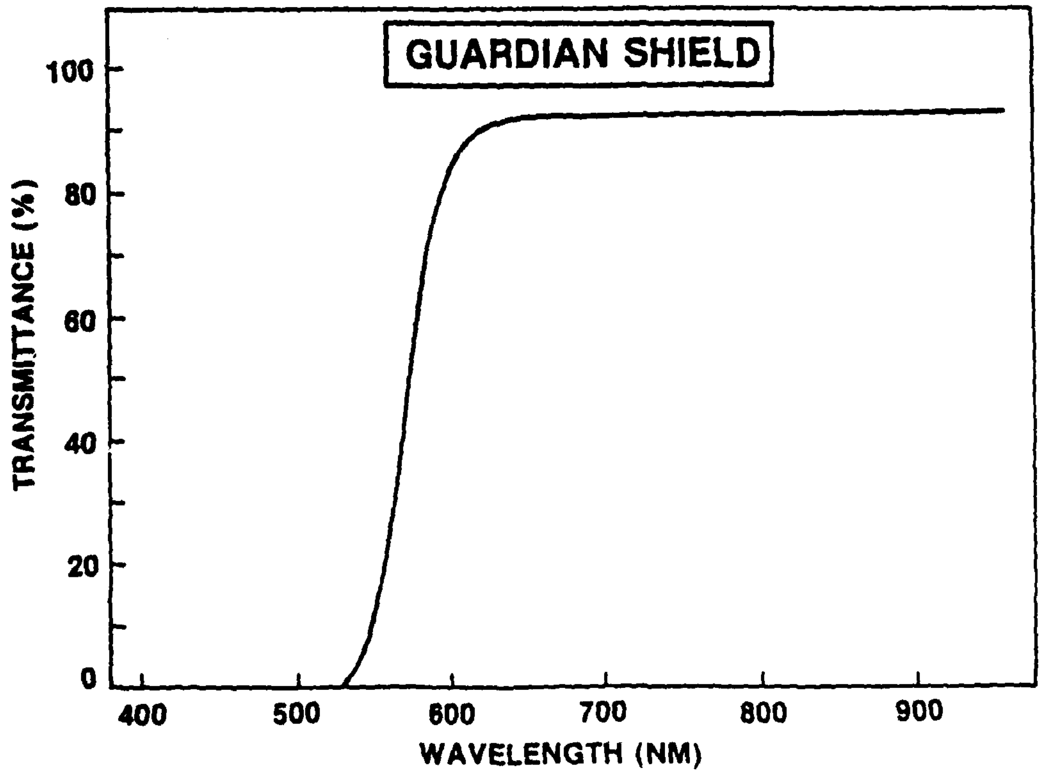


Figure 16. Guardian shield/lens color = orange.

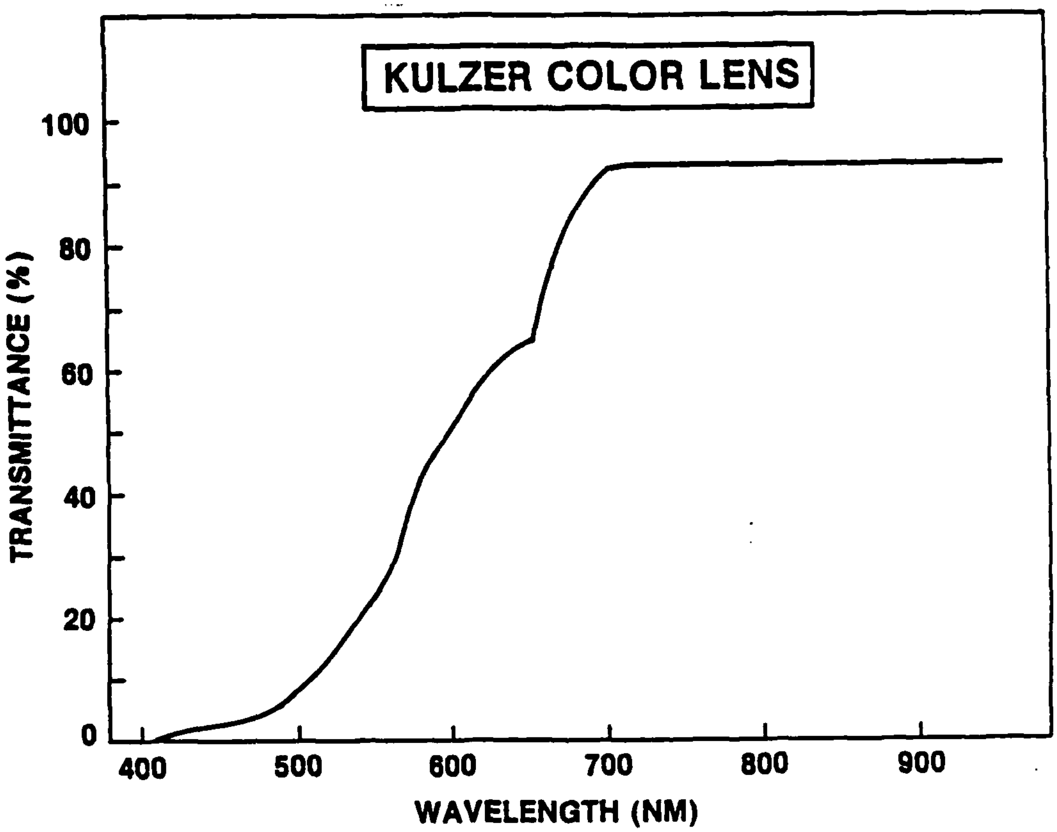


Figure 17. Kulzer color lens/lens color = orange.

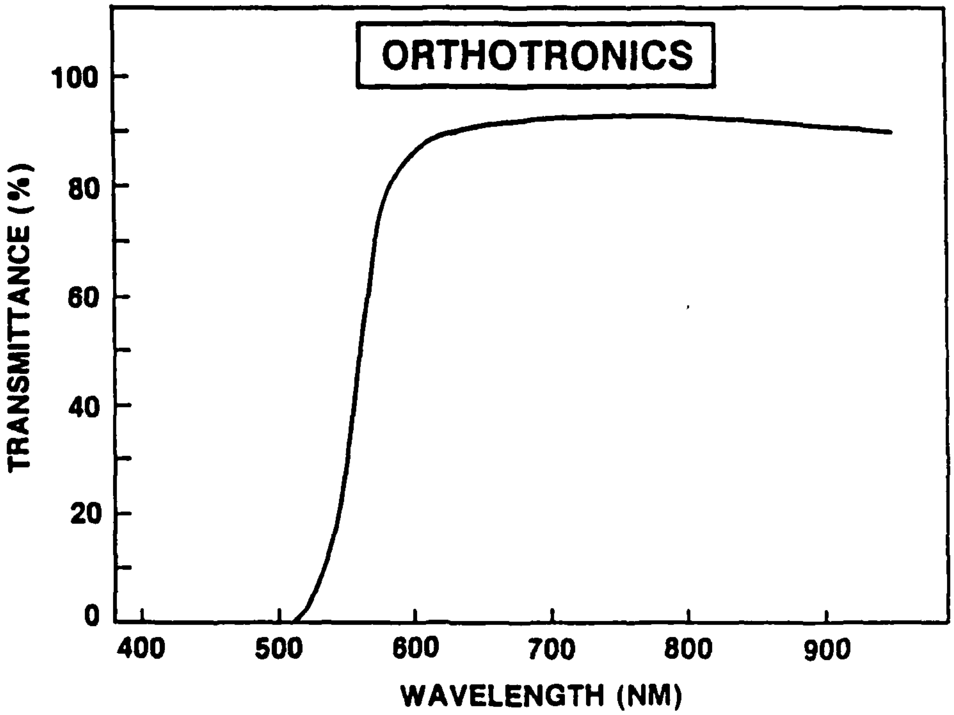


Figure 18. Orthotronics/lens color = orange.

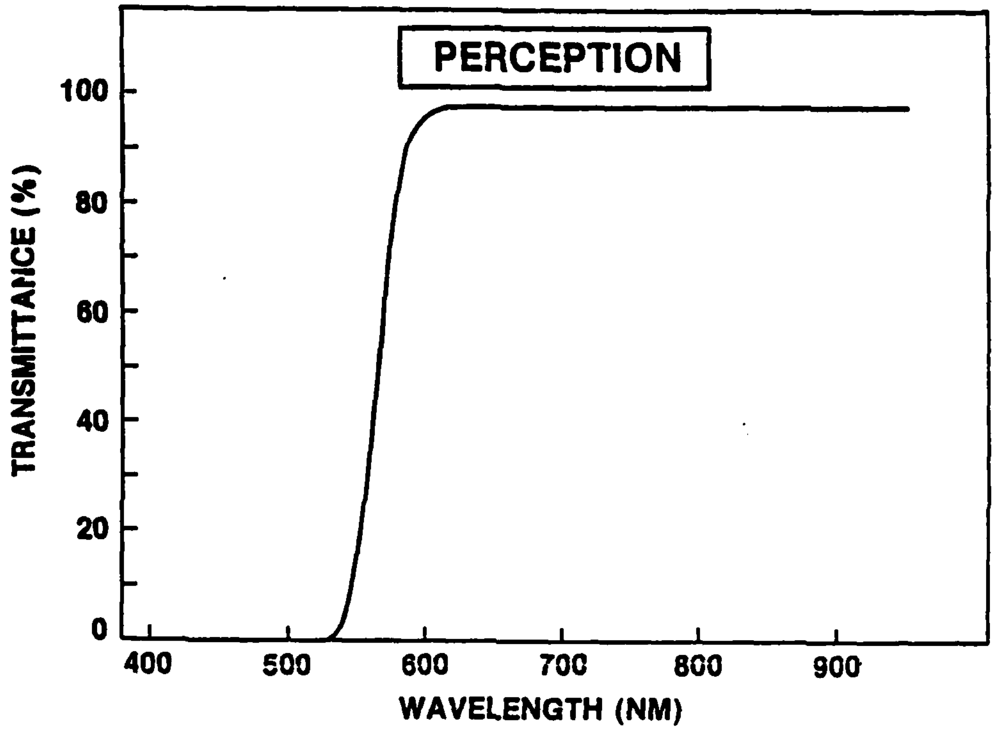


Figure 19. Perception/lens color = orange.

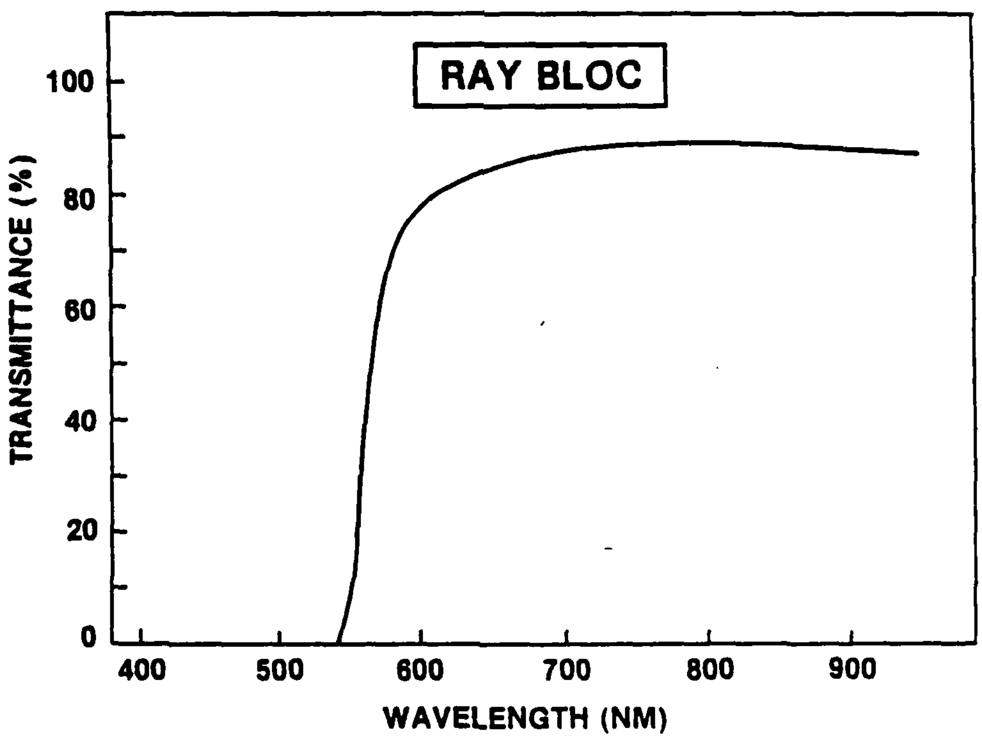


Figure 20. Ray bloc/lens color = orange.

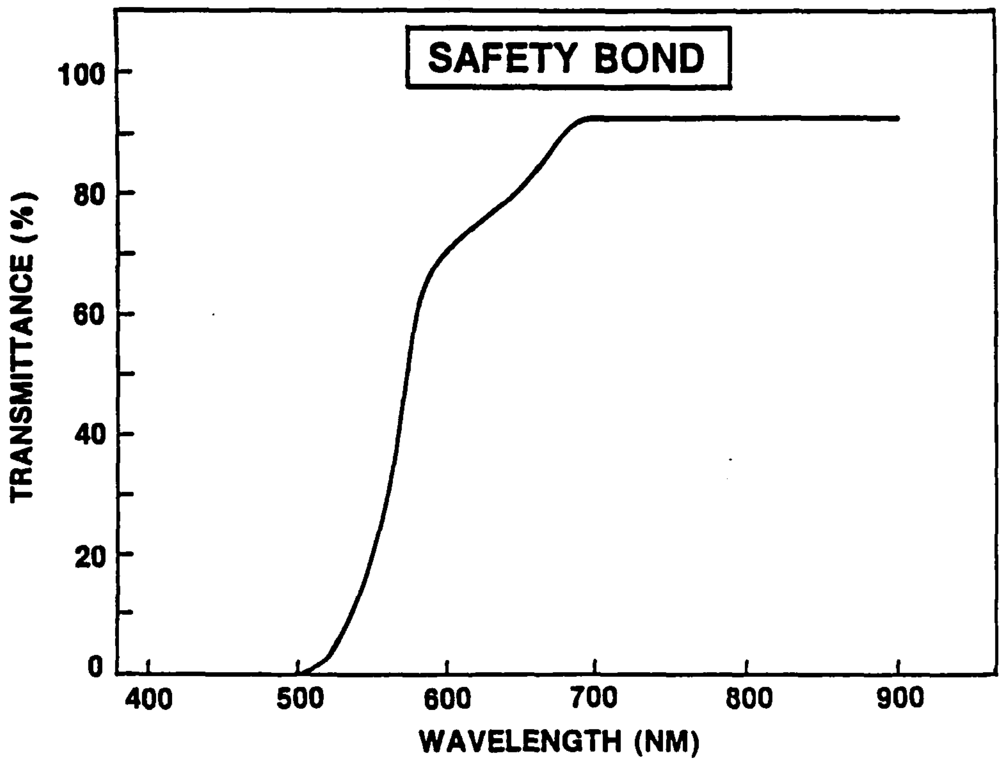


Figure 21. Safety bond/lens color = orange.

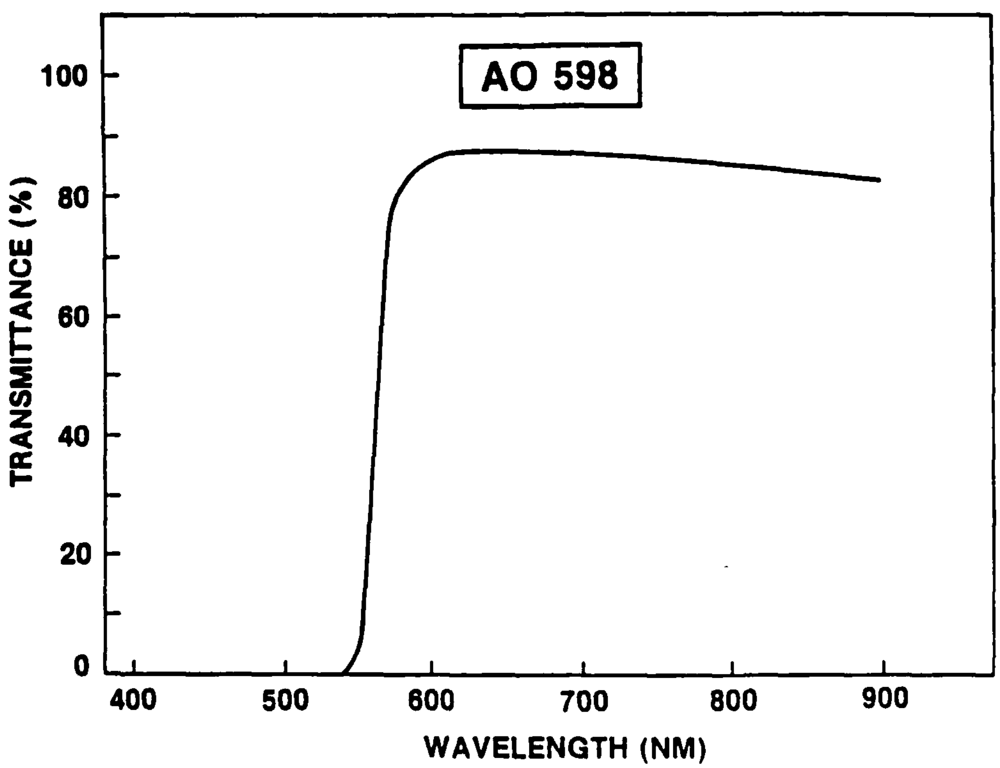


Figure 22. AO #598/lens color = orange.

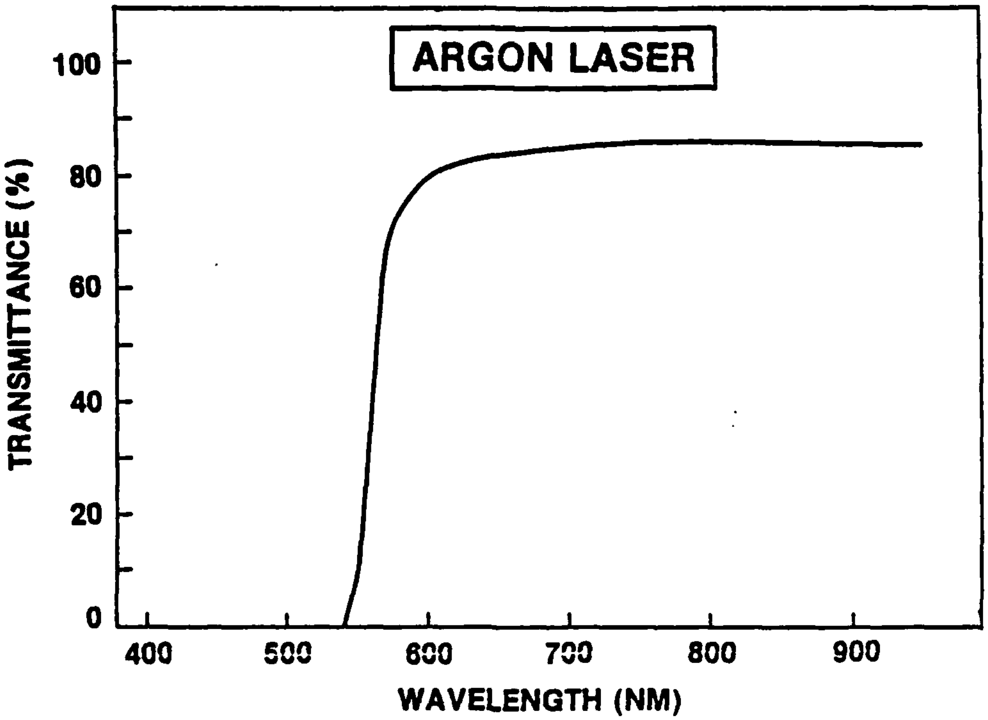


Figure 23. A argon laser/lens color = orange.

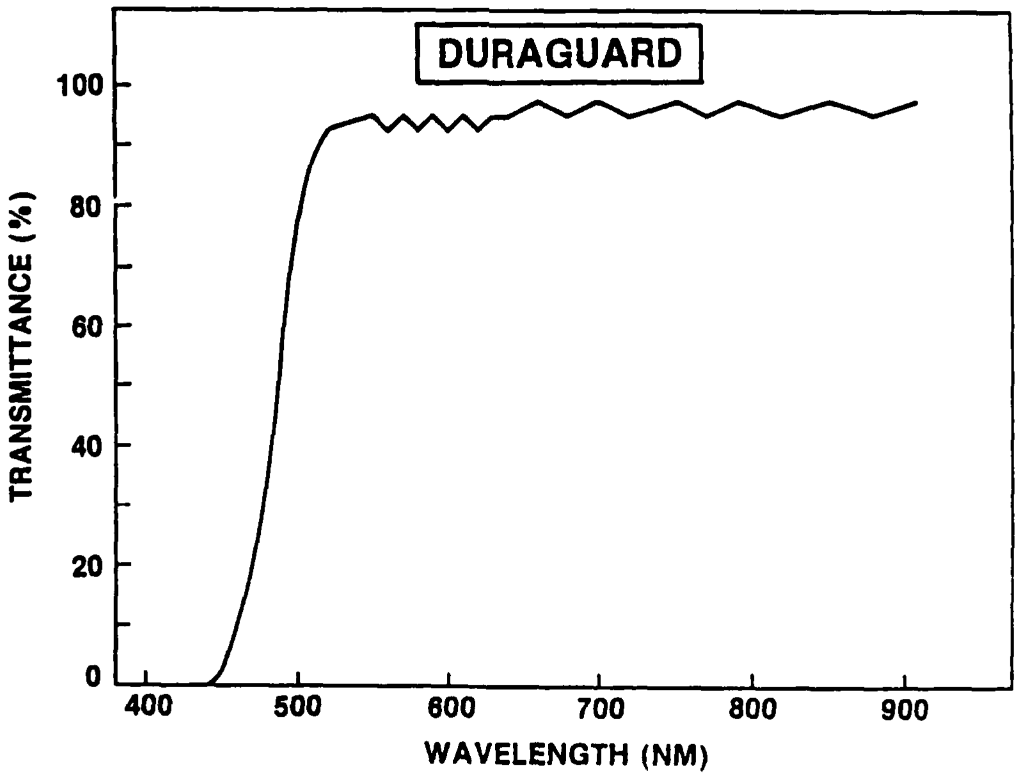


Figure 24. Duraguard/lens color = yellow.

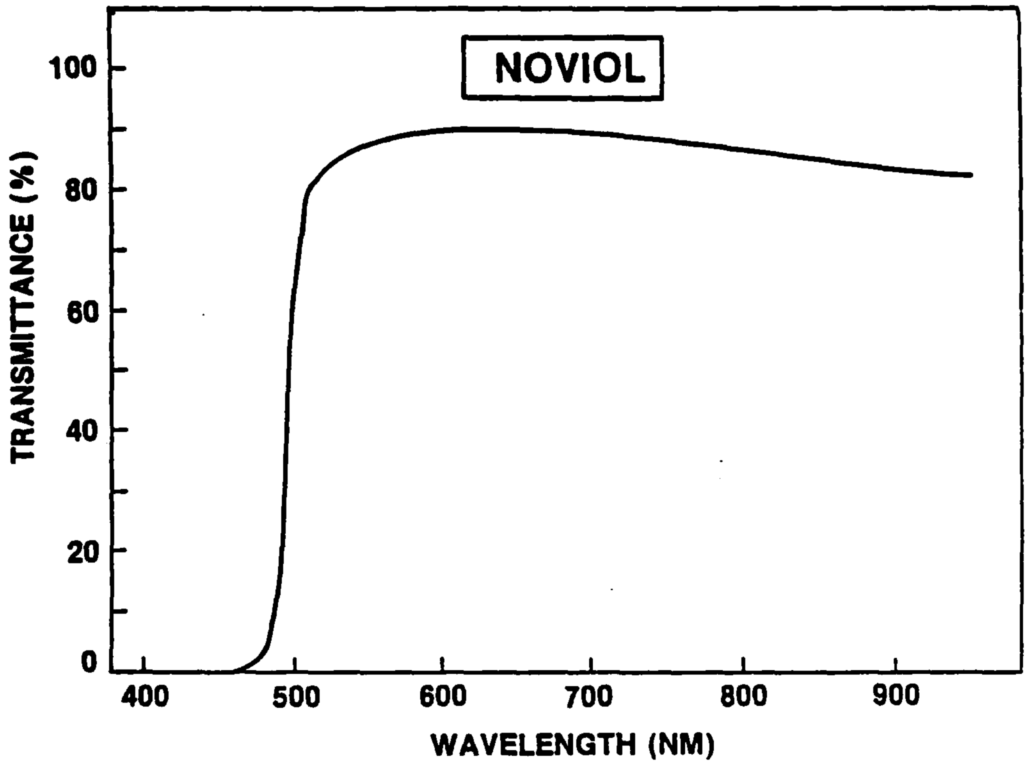


Figure 25. Noviol/lens color = yellow.

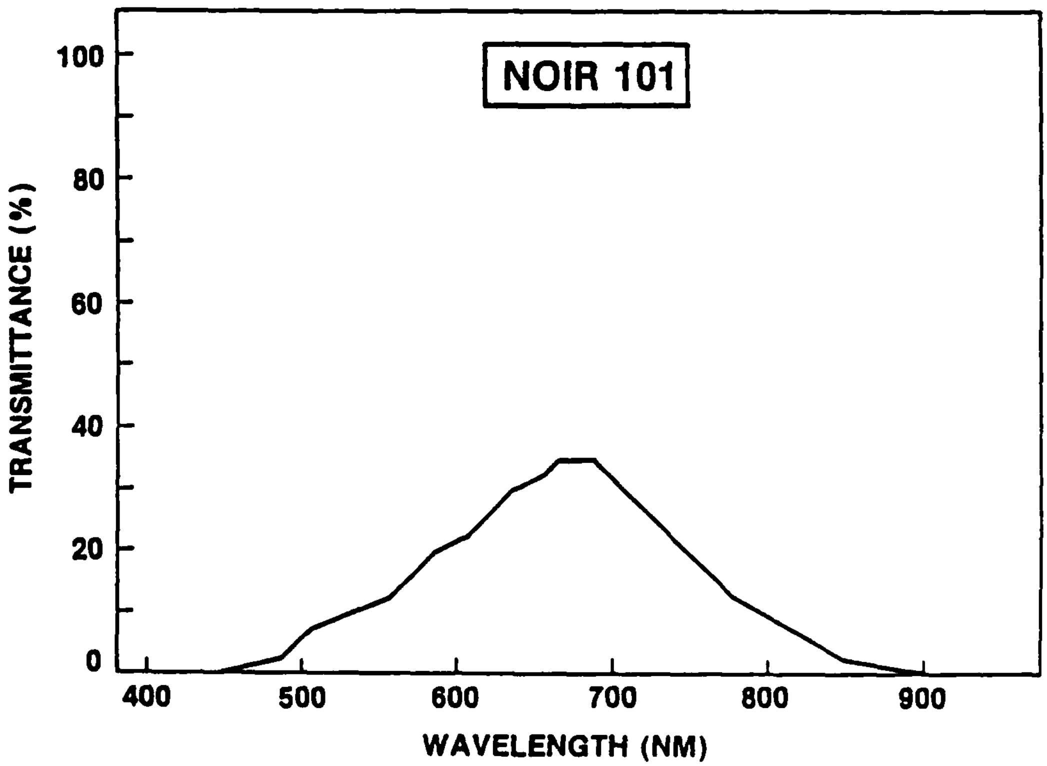


Figure 26. NOIR 101/lens color = brown.

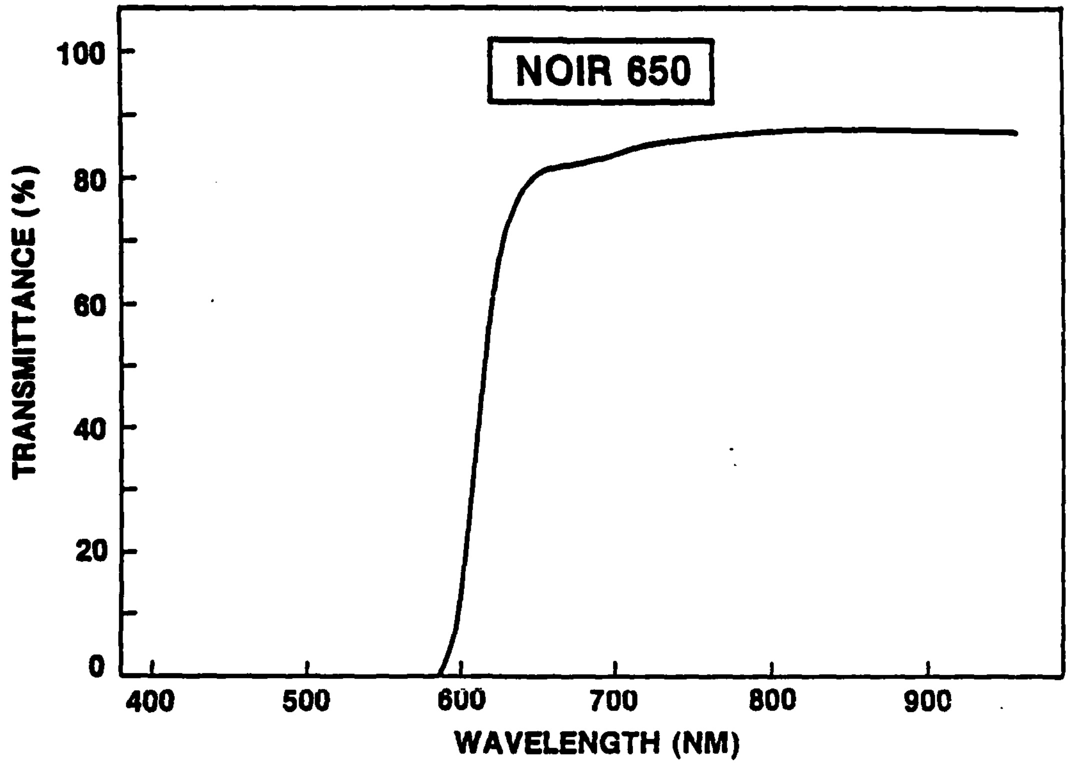


Figure 27. NOIR 650/lens color = red.

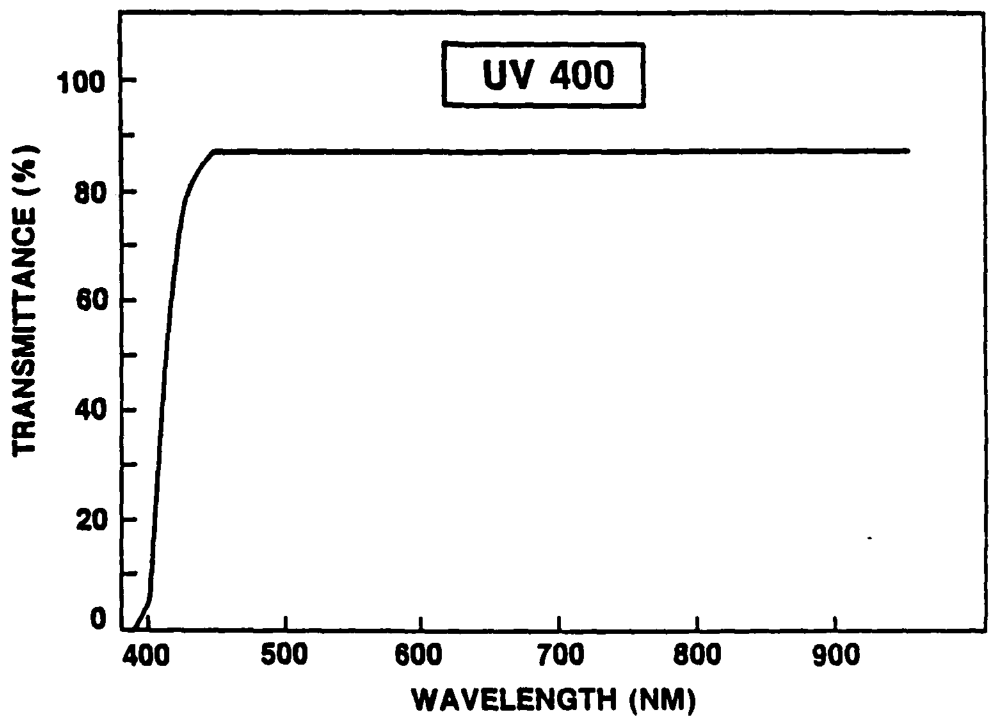


Figure 28. UV 400/lens color = clear (light gray tint).

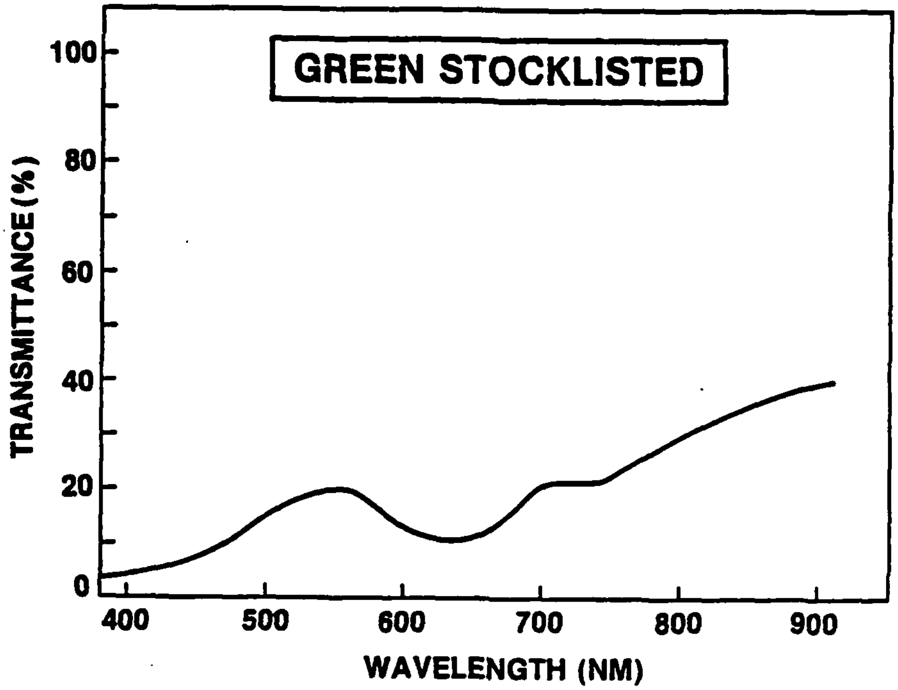


Figure 29. Green stocklisted/lens color = green.

TABLE 1. VISIBLE-LIGHT RESIN CURING UNITS EVALUATED

Unit	Manufacturer
A. Command	Kerr Manufacturing P.O. Box 455 Romulus MI 48174 (800) 521-2854
B. Elipar	ESPE/Premier P.O. Box 111 Norristown PA 19404 (215) 277-3800
C. Fiber-Lite	Dolan-Jenner Industries Blueberry Hill Industrial Park P.O. Box 1020 Woburn MA 01801 (617) 935-7444
D. Heliomat	Vivadent USA P.O. Box 304 Tonawanda NY 14150 (716) 694-2333

Table 1 (continued)

Unit	Manufacturer
E. Insight II	American Midwest 910 W. Oakton St. Des Plaines IL 60018 (312) 640-4800
F. Kavo/Vicon "DLS"	Kavo American Corp. 2200 W. Higgins Road Hoffman Estates IL 60195 (312) 885-3855
G. Optilux	Demetron Research Corp. 5 Ye Olde Road Danbury CT 06810 (203) 748-0030
H. Prisma-Lite	L.D. Caulk Co. Lakeview and Clark Ave. Milford DE 19963 (800) 441-8448
I. Spectra-Lite	Pentron Corp. P.O. Box 771 Wallingford CT 06492 (203) 265-3886
J. Translux	Kulzer Inc. 25251 Pasea de Alicia Suite 200 Laguna Hills CA 92653 (800) 854-4003
K. Visar 2	Den Mat P.O. Box 1759 Santa Maria CA 93456 (800) 235-2441

TABLE 2. SPECTRAL WEIGHTING FUNCTIONS FOR ASSESSING RETINAL HAZARDS

Wavelength (nm)	Thermal hazard function R_λ	Blue-light hazard function B_λ
400	1.0	0.10
405	2.0	0.20
410	4.0	0.40
415	8.0	0.80
420	9.0	0.90
425	9.5	0.95
430	9.8	0.98

435	10	1.0
440	10	1.0
445	9.7	0.97
450	9.4	0.94
455	9.0	0.90
460	8.0	0.80
465	7.0	0.70
470	6.2	0.62
475	5.5	0.55
480	4.5	0.45
485	4.0	0.40
490	2.2	0.22
495	1.6	0.16
500-600	1.0	10 [(450-λ)/50]
600-700	1.0	0.001
700-1050	10 [(700-λ)/505]	0.001
1050-1400	0.2	0.001

TABLE 3. PROTECTIVE LENSES EVALUATED

Lens No.	Lens	Manufacturer
1	BPI New 550's	Brain Power Inc. 4470 S.W. 74 Ave Miami FL 33155
2	Cure Shield	ESPE-Premier 1710 Romano Dr Norristown PA 19404-9981
3	Efos Shield	Efos Inc. 107 Delaware Ave, Suite 1648 Buffalo NY 14202
4	Guardian Shield	Laclede Research 1501 Staff Court Gardena CA 90248
5	Kulzer Color Lens	Kulzer Inc. 10005 Muirlands Blvd, Unit G Irvine CA 92714
6	Orthotronics	Orthotronics 29 North Main St Gloversville NY 12078
7	Perception	Dentsply-Caulk P.O. Box 359 Milford DE 19963
8	Ray Bloc	Carl Parker Assoc 150 Broad Hollow Rd Melville NY 11747

Table 3. (continued)

Lens No.	Lens	Manufacturer
9	Safety Bond	Dr. Vito Accardi 34 Lucille Dix Hills NY 11746
10	AO 598	American Optical 14 Mechanic St Southbridge MA 01550
11	A Argon	Glendale Optical 130 Crossways Park Dr Woodburg NY 11797
12	Duraguard	American Optical 14 Mechanic St Southbridge MA 01550
13	Noviol	American Optical 14 Mechanic St Southbridge MA 01550
14	Noir 101	Recreational Innovations P.O. Box 157 So. Lyon MI 48178
15	Noir 650	Recreational Innovations P.O. Box 157 So. Lyon MI 48178
16	UV 400	Optical Radiation 1300 Optical Dr, Dept J Azusa CA 92702
17	Green Stocklisted	NSN-6520-01-130-7721

TABLE 4. PEAK RADIANCE VALUES

Unit	1st Peak Radiance (watts/$m^2 \cdot Sr \cdot nm$)	1st Peak Wavelength (nm)
A	60.1	490
B	40.3	440
C	164	550
D	45.1	500
E	40.3	490
F	168.4	680
G	161.4	480
H	68.1	480
I	44.1	510
J	39.5	500
K	25.4	470

TABLE 5. INTEGRATED VISIBLE RADIANCE

Unit	Integrated radiance ($watts/Sr \cdot m^2$)	Ratio nonvisible to visible
A	7,500	2.40
B	3,000	0.04
C	18,000	0.95
D	3,000	0.00
E	17,000	1.20
F	8,000	0.56
G	13,000	0.04
H	4,800	0.65
I	6,100	0.50
J	4,400	0.04
K	5,800	1.30

TABLE 6. THERMAL HAZARD

Unit	% of 10 S Weighted integrated radiance
A	7.3%
B	3.7%
C	16.7%
D	3.7%
E	16.0%
F	17.1%
G	8.5%
H	3.7%
I	3.7%
J	5.3%
K	6.0%

TABLE 7. BLUE-LIGHT HAZARD

Unit	Maximum permissible exposure t_{MAX} (min)
A	7.2
B	7.4
C	4.2
D	10.4
E	11.4
F	8.4
G	2.4
H	6.1
I	12.5
J	9.7
K	16.0

TABLE 8. BLUE-LIGHT HAZARD - MAXIMUM PERMISSIBLE EXPOSURE (t_{MAX})

(Maximum recommended direct viewing time in minutes per 24 h from a distance of 25.4 cm (10 in.)

		Lens																
Unit	No lens	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Command	7.2	*	*	*	*	*	*	*	*	*	*	*	52.3	*	*	*	8.6	109.0
Elipar	7.4	*	*	*	*	*	*	*	*	*	*	*	112.6	*	*	*	9.2	139.0
Fiber-Lite	4.2	*	*	*	*	102.9	*	*	*	*	*	*	23.1	59.5	*	*	5.1	58.3
Heliomat	10.4	*	*	*	*	*	*	*	*	*	*	*	65.7	*	*	*	12.4	149.0
Insight II	11.4	*	*	*	*	*	*	*	*	*	*	*	66.1	*	*	*	13.7	160.0
Kavo/Vicon	8.4	*	*	*	*	152.9	*	*	*	*	*	*	35.5	73.5	*	*	10.0	105.7
Optilux	2.4	*	*	*	*	76.0	*	*	*	*	*	*	18.9	92.1	*	*	2.9	37.5
Prisma-Lite	6.1	*	*	*	*	*	*	*	*	*	*	*	42.6	*	*	*	7.3	90.5
Spectra-Lite	12.5	*	*	*	*	*	*	*	*	*	*	*	72.3	*	*	*	15.2	*
Translux	9.7	*	*	*	*	*	*	*	*	*	*	*	73.9	*	*	*	11.8	152.0
Visar-2	16.0	*	*	*	*	*	*	*	*	*	*	*	156.5	*	*	*	19.4	*

* Indicates t_{MAX} value greater than 10^4 s (167 min) with weighted, integrated spectral radiance value below the level considered hazardous even for continuous exposure.

TABLE 9. LUMINOUS TRANSMITTANCE

Lens		Luminous transmittance	Lens color
1	BPI New 550's	0.274	Orange
2	Cure Shield	0.566	Orange
3	Efos Shield	0.479	Orange
4	Guardian Shield	0.409	Orange
5	Kulzer Color Lens	0.327	Orange
6	Orthotronics	0.443	Orange
7	Perception	0.426	Orange
8	Ray Bloc	0.353	Orange
9	Safety Bond	0.342	Orange
10	AO 598	0.400	Orange
11	A Argon	0.371	Orange
12	Duraguard	0.895	Yellow
13	Noviol	0.808	Yellow
14	Noir 101	0.154	Brown
15	Noir 650	0.108	Red
16	UV 400	0.879	Clear (Light gray tint)

END

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